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Assessment of the ROX index as a predictor of invasive ventilation in patients with community-acquired pneumonia

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ABSTRACT

Aims: Community-acquired pneumonia (CAP) is a significant cause of morbidity and mortality worldwide, particularly among elderly patients and those with comorbid conditions. CAP can lead to severe respiratory failure, often necessitating invasive mechanical ventilation (IMV). Early identification of patients at high risk for intubation is crucial for optimizing management and improving outcomes. The ROX index, which incorporates respiratory rate, oxygen saturation, and fraction of inspired oxygen, has emerged as a potential tool for predicting the need for IMV in patients with respiratory distress. This study aims to evaluate the effectiveness of the ROX index in predicting IMV in patients hospitalized with CAP.

Methods: This retrospective cohort study included patients diagnosed with CAP who were admitted to a tertiary healthcare institution between January 1, 2019, and January 1, 2024. The ROX index was calculated at hospital admission using respiratory rate, oxygen saturation (SpO_2), and fraction of inspired oxygen (FiO_2). Severe pneumonia was defined as pneumonia severity index (PSI) class IV or V, and subgroup analyses were conducted for these patients to evaluate the diagnostic performance of the ROX index. The primary outcome was the requirement for IMV, and the predictive ability of the ROX index was evaluated.

Results: A total of 416 patients were included, with 30 (7.2%) requiring invasive mechanical ventilation. The mean ROX index was significantly lower in the intubation group (14.4±4.5) compared to the non-intubation group (23.8±5.4) ($p<0.001$). A ROX index ≤18.7 was identified as the optimal cutoff for predicting IMV, with an AUROC of 0.908. Among patients with severe pneumonia, the ROX index demonstrated an AUROC of 0.831, indicating strong predictive performance in this subgroup.

Conclusion: The ROX index is a valuable tool for predicting the need for invasive mechanical ventilation in patients with CAP, particularly in those with severe pneumonia, making it a useful tool for early risk stratification and clinical decision-making.

Keywords: Critical care, mechanical ventilation, pneumonia

INTRODUCTION

Community-acquired pneumonia (CAP) is a significant public health issue worldwide, with high rates of mortality and morbidity.[1-3] As one of the most common and deadly forms of respiratory infections, CAP particularly leads to severe clinical outcomes in elderly individuals and those with underlying chronic conditions. The increasing elderly population and rising burden of comorbidities have made the clinical management of CAP more complex. Common conditions such as hypertension, diabetes, and chronic lung diseases in this patient group negatively affect the course of pneumonia and increase mortality rates. The annual mortality rate due to CAP ranges from 2% to 50% globally, and it is among the infections that frequently require hospitalization and intensive care unit (ICU) admission.[4-6]

One of the most critical aspects of managing CAP is accurate risk assessment at the onset of the disease. This allows for the early identification of high-risk patients and the prompt application of appropriate treatment strategies. Severe CAP cases that are not addressed early often lead to multiple organ failure and respiratory failure, necessitating invasive mechanical ventilation and ICU admission.[7,8] Accurately predicting the need for intubation in this process enables timely interventions that may prevent the worsening of the disease.

The ROX index is a scoring system developed to predict the success of non-invasive ventilation and the need for intubation in patients with respiratory failure. By combining respiratory rate, oxygen saturation, and fraction of inspired oxygen (FiO_2), the ROX index objectively evaluates a patient's respiratory function and clinical course. The ROX index has been shown to be an effective tool for predicting the need for intubation in patients undergoing non-invasive ventilation and is increasingly being used, particularly in cases of acute respiratory distress.[9,10]

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This study hypothesizes that the ROX index can accurately predict the need for invasive mechanical ventilation in patients with CAP. The primary aim of the study is to evaluate the diagnostic performance of the ROX index in predicting intubation across all patients with CAP. Additionally, as a secondary aim, the study evaluates the performance of the ROX index in predicting intubation specifically in patients with severe pneumonia.

METHODS

This study was conducted with the approval of the İstanbul Yeni Yüzyıl University Clinical Researches Ethics Committee (Date: 04.11.2024, Decision No: 2024/11-1356) and was carried out in accordance with the ethical principles of the Declaration of Helsinki.

This retrospective cohort study included patients diagnosed with CAP who were admitted to the emergency department of a tertiary healthcare institution between January 1, 2019, and January 1, 2024. The inclusion criteria were as follows: patients aged 18 and older, a confirmed diagnosis of CAP, and complete clinical and laboratory data available at the time of hospital admission. Exclusion criteria included the presence of a non-pneumonia diagnosis, incomplete data that would hinder the calculation of the ROX index, and patients transferred from other hospitals. Patients diagnosed with COVID-19 pneumonia or admitted during the COVID-19 pandemic period (March 2020 to December 2022) were excluded to prevent confounding effects caused by changes in pneumonia management during this period.

Demographic data (age, gender), clinical characteristics (vital signs at admission, oxygen therapy parameters, comorbidities), laboratory findings, and the need for invasive mechanical ventilation were retrospectively collected from patient medical records. Patient data were retrospectively collected from electronic medical records. Inclusion and exclusion criteria were applied systematically to identify eligible patients. Clinical and laboratory parameters, including the components required to calculate the ROX index, were extracted uniformly for all patients. The ROX index, calculated as the ratio of oxygen saturation as measured by pulse oximetry (SpO_2) to the fraction of inspired oxygen (FiO_2), divided by the respiratory rate, was assessed upon hospital admission.[11] The ROX index was calculated using the formula: (SpO_2/FiO_2)/respiratory rate. SpO_2 was measured via pulse oximetry as a percentage, FiO_2 was documented as the fraction of inspired oxygen delivered to the patient, and respiratory rate was recorded in breaths per minute. These parameters were obtained at hospital admission and documented in the initial patient records to ensure consistency. The PSI was calculated for all patients at the time of hospital admission using the validated scoring system, which incorporates age, comorbidities, vital signs, and laboratory findings to assess pneumonia severity. Severe pneumonia was defined as patients classified into PSI class IV or V based on the PSI scoring system. This classification was used to identify and analyze the subgroup of patients with severe pneumonia. The primary outcome of the study was the requirement for invasive mechanical ventilation. Non-invasive ventilation strategies, including CPAP or BiPAP, and oxygen supplementation (via nasal cannula, face mask, or high-flow nasal cannula), were applied as clinically indicated to stabilize patients prior to assessing the need for invasive ventilation.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., Armonk, NY, USA) and MedCalc version 20.104 (MedCalc Software Ltd., Ostend, Belgium). Descriptive statistics were calculated for each variable, with continuous variables presented as means±standard deviation (SD) for normally distributed data or medians with interquartile ranges (IQR) for non-normally distributed data. Categorical variables were summarized using frequencies and percentages. The normality of continuous data was assessed with histograms and the Shapiro-Wilk test. Comparisons between groups were conducted using the Student's t-test for normally distributed continuous variables and the Mann-Whitney U test for non-normally distributed continuous variables. Categorical variables were analyzed using the Chi-square test or Fisher's exact test when appropriate.

Receiver operating characteristic (ROC) curve analysis was performed to assess the diagnostic accuracy of the ROX index for predicting intubation, and the area under the ROC curve (AUROC) was calculated. Sensitivity, specificity, positive likelihood ratio (+LR), and negative likelihood ratio (–LR) were derived at different cutoffs, with the optimal cutoff determined using Youden's Index. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Of the initial 725 patients identified during the study period, 309 were excluded for the following reasons: 198 due to COVID-19 pneumonia, 71 due to incomplete data that hindered the calculation of the ROX index, and 40 due to transfer from other hospitals. A total of 416 patients were included in the study, with 386 (92.8%) in the non-intubation group and 30 (7.2%) in the intubation group. The mean age was statistically significantly higher in the intubation group (72.2±13.4 years) compared to the non-intubation group (54±10.6 years) ($p<0.001$, mean difference 18.3 years, 95% CI 13.2–23.3) (**Table 1**). The proportion of male patients was 70% (n=21) in the intubation group and 63% (n=243) in the non-intubation group, with no statistically significant difference ($p=0.440$).

Hypertension was observed in 50% (n=15) of the intubation group and 33.9% (n=131) of the non-intubation group, with no statistically significant difference ($p=0.076$). Diabetes mellitus was present in 33.3% (n=10) of the intubation group and 21.2% (n=82) of the non-intubation group ($p=0.124$). Coronary artery disease was statistically significantly more frequent in the intubation group, with 33.3% (n=10) compared to 14% (n=54) in the non-intubation group ($p=0.005$). Heart failure was also statistically significantly more common in the intubation group, with 40% (n=12) versus 9.3% (n=36) in the non-intubation group ($p<0.001$). Stroke was found in 20% (n=6) of intubated patients compared to 7.3% (n=28) in non-intubated patients, showing statistical significance ($p=0.014$).

Table 1. Demographics, comorbidities, and symptoms of patients

Variable	Non-intubation (n=386)	Intubation (n=30)	p	Mean difference (95% CI)
Demographics				
Age (years) (mean±SD)	54±10.6	72.2±13.4	<0.001	18.3 (13.2-23.3)
Gender (male) (count [%])	243 (63%)	21 (70%)	0.440	
Comorbidities				
Hypertension (count [%])	131 (33.9%)	15 (50%)	0.076	
Diabetes mellitus (count [%])	82 (21.2%)	10 (33.3%)	0.124	
CAD (count [%])	54 (14%)	10 (33.3%)	0.005	
Heart failure (count [%])	36 (9.3%)	12 (40%)	<0.001	
Stroke (count [%])	28 (7.3%)	6 (20%)	0.014	
Chronic kidney disease (count [%])	23 (6%)	8 (26.7%)	<0.001	
Symptoms and signs				
Cough (count [%])	304 (78.8%)	21 (70%)	0.264	
Shortness of breath (count [%])	248 (64.2%)	28 (93.3%)	0.001	
Fever (count [%])	190 (49.2%)	17 (56.7%)	0.432	
Pleuritic pain (count [%])	90 (23.3%)	12 (40%)	0.041	
Impaired consciousness (count [%])	49 (12.7%)	8 (26.7%)	0.032	

CAD: Coronary artery disease, CI: Confidence interval, SD: Standard deviation

Chronic kidney disease was statistically significantly higher in the intubation group at 26.7% (n=8) compared to 6% (n=23) in the non-intubation group (p<0.001) (**Table 1**).

Regarding symptoms, cough was present in 70% (n=21) of the intubation group and 78.8% (n=304) of the non-intubation group, with no statistically significant difference (p=0.264). Shortness of breath was statistically significantly more common in the intubation group, with 93.3% (n=28) versus 64.2% (n=248) in the non-intubation group (p=0.001). Fever was noted in 56.7% (n=17) of the intubation group and 49.2% (n=190) of the non-intubation group, with no statistically significant difference (p=0.432). Pleuritic pain was observed in 40% (n=12) of the intubation group compared to 23.3% (n=90) of the non-intubation group, reaching statistical significance (p=0.041). Impaired consciousness was statistically significantly more common in the intubation group (26.7%, n=8) compared to the non-intubation group (12.7%, n=49) (p=0.032) (**Table 1**).

In terms of clinical parameters, heart rate was statistically significantly higher in the intubation group, with a mean of 92.9±15.4 beats/min compared to 85.6±10.3 beats/min in the non-intubation group (p<0.001, mean difference 7.3 beats/min, 95% CI 3.3-11.3). Systolic blood pressure (SBP) was statistically significantly lower in the intubation group, with a mean of 101.6±19.7 mmHg compared to 122.3±15.8 mmHg in the non-intubation group (p<0.001, mean difference 20.7 mmHg, 95% CI 14.7-26.6). Diastolic blood pressure (DBP) was also statistically significantly lower in the intubation group, with a mean of 65.9±19.5 mmHg compared to 81.9±12.7 mmHg in the non-intubation group (p<0.001, mean difference 16 mmHg, 95% CI 11-20.9). The respiratory rate was higher in the intubation group, with a median of 19 breaths/min [IQR 15-27] compared to 14 breaths/min [IQR 11-19] in the non-intubation group (p<0.001). Peripheral oxygen saturation (SPO_2) was statistically significantly lower in the intubation group, with a median of 83.5% [IQR 77-88.3] compared to 92% [IQR 90-94] in the non-intubation group (p<0.001). The fraction of inspired oxygen (FiO_2) was higher in the intubation group, with a median of 35% [IQR 30–43.8] compared to 25% [IQR 25–29] in the non-intubation group (p<0.001). The ROX index was statistically significantly lower in the intubation group, with a mean of 14.4±4.5 compared to 23.8±5.4 in the non-intubation group (p<0.001, mean difference 9.4, 95% CI 7.4-11.4). The pneumonia severity index (PSI) was statistically significantly higher in the intubation group (115 [IQR 97-135]) compared to the non-intubation group (67 [IQR 57.8-79]) (p<0.001). Severe pneumonia was significantly more frequent in the intubation group (56.7%, n=17) than in the non-intubation group (10.6%, n=41) (p<0.001) (**Table 2**).

In laboratory parameters, the mean white blood cell count was statistically significantly higher in the intubation group (15105±2014 cells/μL) compared to the non-intubation group (13972±2041 cells/μL) (p=0.004, mean difference 1133 cells/μL, 95% CI 356-1909). Creatinine levels were higher in the intubation group, with a median of 2.35 mg/dl [IQR 1.48-3.83] compared to 0.9 mg/dl [IQR 0.5–1.3] in the non-intubation group (p<0.001). Lactate levels were also statistically significantly higher in the intubation group, with a median of 3.2 mmol/L [IQR 2.38-4.23] compared to 1.9 mmol/L [IQR 1.6-2.3] in the non-intubation group (p<0.001). The partial pressure of oxygen in arterial blood (PaO_2) was statistically significantly lower in the intubation group, with a median of 40 mmHg [IQR 35-50] compared to 55 mmHg [IQR 52-59] in the non-intubation group (p<0.001) (**Table 2**).

The predictive value of the ROX index for intubation was evaluated with an area under the ROC curve (AUROC) of 0.908 (95% CI 0.877–0.934), with a statistically significant p-value of <0.001 (**Figure 1**). The Youden Index J was 0.722, and the optimal criterion for intubation was ≤18.7. Among patients with severe pneumonia, the ROX index demonstrated an AUROC of 0.831 (95% CI 0.709-0.916), with a statistically significant p-value of <0.001, and an optimal criterion of ≤15.1 (Youden Index J=0.756) (**Table 3, Figure 2**).

Table 2. Clinical parameters and laboratory results

Variable	Non-intubation (n=386)	Intubation (n=30)	p	Mean difference (95% CI)
Vital signs				
Heart rate (beats/min) (mean±SD)	85.6±10.3	92.9±15.4	<0.001	7.3 (3.3-11.3)
SBP (mmHg) (mean±SD)	122.3±15.8	101.6±19.7	<0.001	20.7 (14.7-26.6)
DBP (mmHg) (mean±SD)	81.9±12.7	65.9±19.5	<0.001	16 (11-20.9)
Respiratory rate (breaths/min) (median [IQR])	14 [11-19]	19 [15-27]	<0.001	
SPO_2 (%) (median [IQR])	92 [90-94]	83.5 [77-88.3]	<0.001	
FiO_2 (%) (median [IQR])	25 [25-29]	35 [30-43.8]	<0.001	
ROX (mean±SD)	23.8±5.4	14.4±4.5	<0.001	9.4 (7.4-11.4)
Laboratory parameters				
White blood cell (10^3/μL) (mean±SD)	13972±2041	15105±2014	0.004	1133 (356-1909)
Creatinine (mg/dl) (median [IQR])	0.9 [0.5-1.3]	2.35 [1.48-3.83]	<0.001	
Lactate (mmol/L) (median [IQR])	1.9 [1.6-2.3]	3.2 [2.38-4.23]	<0.001	
PaO_2 (mmHg) (median [IQR])	55 [52-59]	40 [35-50]	<0.001	
PSI (median [IQR])	67 [57.8-79]	115 [97-135]	<0.001	
Severe pneumonia (count [%])	41 [10.6%]	17 [56.7%]	<0.001	

SBP: Systolic blood pressure, DBP: Diastolic blood pressure, SPO_2: Peripheral oxygen saturation, FiO_2: Fraction of inspired oxygen, ROX: Respiratory rate-oxygenation index, PaO_2: Partial pressure of oxygen in arterial blood, PSI: Pneumonia severity index, SD: Standard deviation

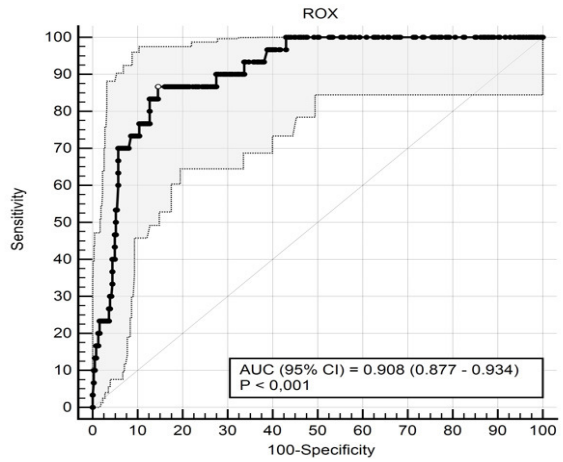

Figure 1. Receiver operating characteristic curve of the respiratory rate-oxygenation index for predicting intubation

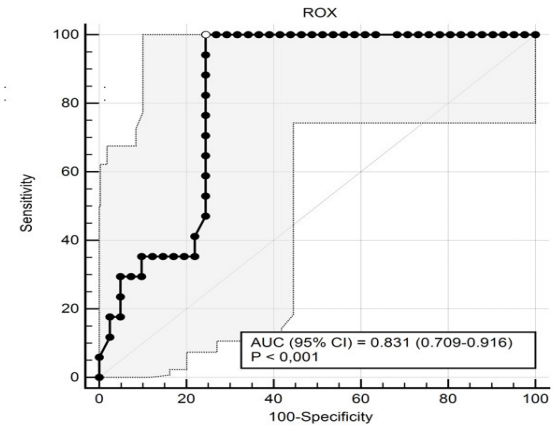

Figure 2. Receiver operating characteristic curve of the respiratory rate-oxygenation index for predicting intubation among severe pneumonia subset

DISCUSSION

The most important finding of our study is that the ROX index can be a useful tool in predicting the need for invasive mechanical ventilation in patients hospitalized with CAP. Our results demonstrate that the ROX index is a reliable tool for identifying patients at high risk for invasive mechanical ventilation, allowing clinicians to prioritize early interventions. Its consistent performance across the entire study population underscores its potential role in routine CAP management. In patients with severe pneumonia, the ROX index proved particularly useful for distinguishing those with significant respiratory effort who may benefit from advanced respiratory support. This finding highlights the practical applicability of the ROX index in guiding clinical decisions, especially in critically ill populations where timely and accurate risk stratification can significantly impact outcomes. Moreover, its simplicity and non-invasive nature make it an ideal tool for resource-limited settings or situations requiring rapid decision-making.

CAP is a serious infectious disease with high morbidity and mortality rates worldwide. This disease, which can progress more severely in elderly patients and those with comorbidities, often requires ICU admission and invasive mechanical ventilation. CAP involves inflammatory processes that severely impair lung function, leading to respiratory failure and increasing the risk of multiple organ failure.[12-14] Patients requiring intensive care are generally in the advanced stages of respiratory failure, making the early identification of these patients and the prediction of intubation needs crucial to reducing mortality. Prognostic tools like the ROX index play a significant role in predicting the clinical course of these

Table 3. Diagnostic performance of respiratory rate-oxygenation index for predicting intubation

Cohort	AUROC (95% CI)	p	Youden index J	Criterion
All patients	0.908 (0.877-0.934)	<0.001	0.722	≤18.7
Severe pneumonia subset	0.831 (0.709-0.916)	<0.001	0.756	≤15.1

AUROC: Receiver operating characteristic curve

patients and help optimize management, especially in settings with limited ICU capacity.[15]

The importance of the ROX index in clinical practice has become even more evident in areas with limited ICU capacity and during large-scale health crises such as pandemics. During the COVID-19 pandemic, when ICU admissions and the need for intubation dramatically increased, the ROX index's ability to predict ventilation needs was utilized as a critical tool for optimizing the use of healthcare resources.[16,17] It has been shown that the ROX index can contribute to clinical decision-making by predicting the need for intubation in situations where ICU beds are limited or when rapid decision-making is required during health crises.[18] In such cases, objective measures like the ROX index can guide healthcare providers to ensure timely and appropriate interventions.

In this study, we found that a lower ROX index was significantly associated with the need for IMV in patients with CAP. This highlights the effectiveness of the ROX index as a predictor for IMV, allowing for early identification of high-risk patients. Similarly, Reyes et al.[19] demonstrated that the ROX index was a reliable tool for predicting IMV in CAP patients. Additionally, Suliman et al.[20] reported that the ROX index successfully predicted the risk of intubation in COVID-19 pneumonia patients, further supporting the utility of the ROX index in respiratory failure scenarios. These studies have demonstrated the utility of the ROX index in various respiratory conditions, our findings provide additional evidence of its specific applicability in CAP and severe pneumonia patients, emphasizing its potential for guiding respiratory support strategies. However, while the ROX index offers considerable utility in predicting the need for invasive mechanical ventilation, its benefits are most pronounced in resource-limited settings or for early risk stratification. In contrast, its use as a routine ICU triage tool for pneumonia requires further validation in diverse clinical contexts.

Limitations

This study has several limitations. First, as a single-center retrospective study, the generalizability of the results may be limited to similar healthcare settings. Additionally, the study relied on medical record data, which could be subject to inaccuracies or missing information. Another limitation is the exclusion of patients who were transferred from other hospitals or those with incomplete data, which may have influenced the study's outcomes. Moreover, the study did not account for other prognostic indices or biomarkers that could potentially improve the prediction of invasive mechanical ventilation in CAP. Additionally the exclusion of patients from the COVID-19 pandemic period limits the generalizability of our findings to this specific context, as pneumonia management strategies during the pandemic differed significantly.

CONCLUSION

This study highlights the potential of the ROX index as a valuable tool for predicting the need for invasive mechanical ventilation in patients with community-acquired pneumonia. By enabling early identification of high-risk patients, the ROX index facilitates timely and targeted interventions, particularly in critically ill populations such as those with severe pneumonia. Its simplicity, non-invasive nature, and applicability in resource-limited settings make it a practical option for clinical use. However, further multicenter studies are warranted to validate its utility across diverse healthcare settings and refine its application in routine practice.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was conducted with the approval of the İstanbul Yeni Yüzyıl University Clinical Researches Ethics Committee (Date: 04.11.2024, Decision No: 2024/11-1356).

Informed Consent

Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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